

Article

The Key Impact on Water Quality on Coral Reefs in Kenting National Park

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Abstract: Southern Taiwan's Kenting National Park is a popular retreating place for many domestic and international tourists, with increasing tourist numbers potentially over-burdening the coastal ecosystems. To better understand human impacts, a long-term ecological research program was initiated in 2001 to track water quality at 14 coral reef-abutting sites throughout the park since then. Extracting the data from this 20-year survey, we found that increasing in the nutrient levels during the summer rainy season, together with the drops in salinity led by freshwater inputs (land- & rainfall-derived), was the main impact to coral reef ecosystem of Kenting. Cluster analysis further confirmed the nutrient influx was mainly attributed to the local discharge outlets with dense of villages and hotels at upstream. Therefore, more efforts are needed to input to control tourist number, treat waste water discharge and strengthen land protection facilities.

Keywords: anthropogenic impacts; coral reefs; rainfall; nutrients; seawater quality



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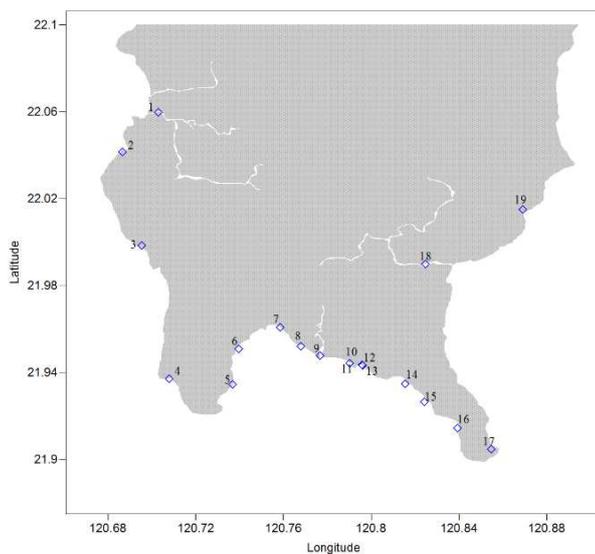
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1. Introduction

Kenting National Park (KNP) is located at the southernmost tip of Taiwan, and the plethora of beaches and vibrant coral reefs are a draw for myriad domestic and international tourists. Unfortunately, the pre-Covid tourism boom (3 million in 2001 to 8 million in 2018) has led to increasing coastal development, sewage and other pollutant discharge, and eutrophication [1–3]; high nitrogen and suspended solid (SS) levels have even been linked to coral reef decline in the area [3], with more direct impacts of tourists (e.g., physical damage to coral colonies) having also been documented [4]. The SS, high nutrient loads, and pathogenic bacteria are presumably land-based, entering the ocean via channels or creeks during the May to September rainy season; such runoff can also include fertilizers and pesticides used in local agriculture [4]. Given these threats, KNP initiated a long-term ecological research (LTER) program in 2001, with data collected until 2019. There has been a focus on nearshore environments abutting coral reef ecosystems (N = 19 sites). Herein we sought to use multivariate statistical approaches, namely principal components analysis (PCA) and cluster analysis (CA), to uncover relationships among seawater quality parameters across the LTER study sites, *sensu* [5–11]. The overarching goal was to use this approach to better understand spatio-temporal variation in seawater quality in this ecologically rich bio-region.

2. Materials and Methods

The KNP LTER sample sites are shown in Figure 1, and seawater quality was assessed at regular intervals between 2001 and 2019. The following parameters were assessed as in our prior works [3,4]. Practically, quality control (QC) for sampling equipment and field measurement procedures, including those for temperature, salinity, pH, and dissolved oxygen (DO), were conducted in situ following government QA/QC regulations. The remaining water samples were preserved at 4 °C and returned to the laboratory for analysis of the following parameters: pH, five days of biochemical oxygen demand (BOD5), nutrients (nitrite, nitrate and phosphate, ammonia) chlorophyll-*a*, suspended solids, and turbidity.



No.	Latitude	Longitude	Station name
1	22.05968	120.7028	Bao-Li Stream
2	22.04153	120.68634	Hou-Wan
3	21.99850	120.69522	Wan-Li-Tung
4	21.93693	120.70789	Bai-Sha
5	21.93436	120.73685	Nuclear power plant outlet (NPP-OL)
6	21.95088	120.73972	Hou-Bi-Hou
7	21.96073	120.75829	Nan-Wan
8	21.95202	120.7678	Tan-Zi
9	21.94787	120.7767	Shir-Neou Stream
10	21.94428	120.7901	Kenting Outlet
11	21.94422	120.7898	Kenting
12	21.94353	120.7957	Caesar Beach Outlet
13	21.94324	120.7959	Caesar
14	21.93481	120.81541	Tsuan-Fan-Shir
15	21.92630	120.8242	Banana Bay
16	21.91454	120.8393	Sar-Dau
17	21.90467	120.85477	Long-Keng
18	21.99002	120.82475	Kang-Koi Stream
19	22.00824	120.86881	Jia-Lo-Shuei

Figure 1. Map of study site and appended table with GPS coordinates.

The measurements of temperature and salinity were carried out in situ with a CTD (conductivity, temperature, and depth [pressure]) instrument (Sea-Bird Electronics Model 19 plus) on the research vessel Ocean Research III and/or by the EPA/ROC (Taipei) technique on fishing boats. The precision for temperature was ± 0.05 °C and the accuracy and precision for salinity were ± 0.003 and ± 0.023 psu, respectively. DO was measured by the Winkler method with an accuracy of ± 0.04 mg/L and a precision of $\pm 1.2\%$. The precision and accuracy (recovery of a spiked glucose standard) of BOD (five days) measurements were $\pm 2.38\%$ and $98.3 \pm 7.7\%$, respectively, and the values were subsequently checked with the control chart.

Analysis of nutrients and ammonium was conducted as followings. Immediately after collection, water samples were stored in a cooler at 4 °C and returned to the laboratory for analysis of ammonia and nutrients. A Flow Injection Analyzer (FIA) and spectrophotometer (Hitachi model U-3000) were used to conduct analysis of ammonia, nitrate, nitrite, phosphate and silicate [12–15].

These data (with the exception of temperature, which was omitted) were analyzed by PCA, hierarchical CA, and discriminant analysis (DA). PCA was used to determine relationships among seawater quality parameters and similarity among sites, with CA used to corroborate the inter-site relationships (Ward’s method of Euclidean distances; depicted as a dendrogram). DA was used to statistically assign sites to particular groups using a predictive model based on the seawater quality parameters. We hypothesized that sites would cluster by anthropogenic input (namely nutrient loads).

3. Results and Discussion

Overall, there were negative correlations between salinity and (1) nutrients and (2) SS (Table 1). This is likely because drops in salinity are associated with influx of land-based freshwater, which can carry high nutrient loads. BOD₅ was positively correlated with turbidity, SS, and nutrients (Table 1), including ammonia (Figure 2B). In contrast, ammonia concentration was negatively correlated with DO (Figure 2A), particularly at the stream and outlet sites. Streams and outlet station were particularly affected by rainfall and sewage discharge. In Table 1, total counts of coliform bacterial (TCB) showed no correlation with any of water parameters measured in this survey, which seemed to discount the impact of sewage. However, most of the seasons displayed high counts of coliform bacteria (median values = 4.88×10^3 colony-forming units (cfu)/100 mL, n = 20) in the water samples collected from the streams and outlet station. Due to lack of long term data on TCB, more information is required to explain this phenomenon. At the Kenting outlet station, a high BOD₅ value was measured alongside a DO saturation of 139%; this could be evidence for high concentrations of phytoplankton and/or dense of coral population (which would provide oxygen at high concentrations via photosynthesis). In addition, there was a significant positive correlation between DO and pH (Figure 2C); this was likely driven by photosynthesis, which would increase the pH.

After normalizing the data, *sensu* [16], the first two principal components explained 43% of the variation (Table 2). PC1 loadings (Table 3) were dominated by silica, nitrate, and salinity (negatively correlated with silica & nitrate), with DO and O₂ saturation featuring the highest loadings within PC2 (16.8% of the variance). In the rotated component matrix (Table 4), the total variance explained by components 1, 2, and 3 for spring were 22, 18, and 15%, respectively, and the dominant seawater quality parameters were turbidity, DO, salinity (negatively correlated with silica), and two nutrients (N, P). The negative relationship between silica and salinity was likely due to rainfall [3]. This finding was also consistent with the impact of rainfall on the water quality of coral reef [17–19], especially from agriculture land [20]. The nutrient influx along with rainfall would be a significant factor to deteriorate coral health [17]. Summer (34, 17, and 13% for components 1, 2, and 3, respectively) trends were mainly related to salinity (negatively correlated with N & P), DO, turbidity, and N-based nutrients; with fall (28, 19, and 14%, respectively) ones related to salinity (negatively correlated with silica), DO, nutrients (N, P), and turbidity. Winter (26, 20, and 12%, respectively) trends were driven by DO, salinity (negatively correlated with silica), nutrients (N, P), and turbidity. Wet and dry season trends were mainly related to DO, salinity (negative correlated with silica), turbidity, and nutrients (P, N). Positive loading of PC3 were SS and turbidity, both of which are affected by rainfall, run-off, river discharge, and typhoons [3]. Finally, PC4 featured positive loadings of phosphate, nitrite, and ammonium (i.e., likely anthropogenic pollutants). Based on the PCA, the wet season water quality was distinct from that of the dry season.

Table 1. Correlation coefficients (R) among seawater quality parameters. DO: dissolved oxygen; O₂ sat.: oxygen saturation; Chl-*a*: chlorophyll *a*; SS: suspended sediments; TCB: total coliform bacteria. (*: $p < 0.05$; **: $p < 0.01$).

	Salinity	pH	DO	O ₂ sat.	BOD ₅	NO ₃	NO ₂	PO ₄	SiO ₂	NH ₃	Turbidity	Chl- <i>a</i>	SS
pH	0.03												
DO	0	0.182											
O ₂ sat.	0.119	0.259	0.944 **										
BOD ₅	-0.243	0.126	-0.445 **	-0.353 **									
NO ₃	-0.546 **	-0.423 **	-0.024	-0.142	-0.026								
NO ₂	-0.501 **	-0.135	-0.007	-0.067	0.113	0.576 **							
PO ₄	-0.585 **	-0.088	-0.036	-0.112	0.188	0.621 **	0.961 **						
SiO ₂	-0.915 **	-0.137	0.07	-0.072	0.133	0.516 **	0.335 *	0.396 **					
NH ₃	-0.487 **	-0.183	-0.011	-0.097	0.113	0.579 **	0.982 **	0.955 **	0.318 *				
Turbidity	-0.098	0.044	-0.302 *	-0.22	0.385 **	0.091	0.254	0.247	0.071	0.225			
Chl- <i>a</i>	0.002	0.082	-0.023	-0.057	0.208	-0.076	-0.021	-0.024	-0.017	0.046	-0.028		
SS	-0.327 *	-0.031	-0.167	-0.151	0.391 **	0.343 *	0.688 **	0.65 **	0.244	0.662 **	0.814 **	-0.01	
TCB	-0.124	-0.112	-0.014	-0.008	-0.038	0.204	-0.009	-0.031	0.261	-0.017	0.09	0.11	0.065

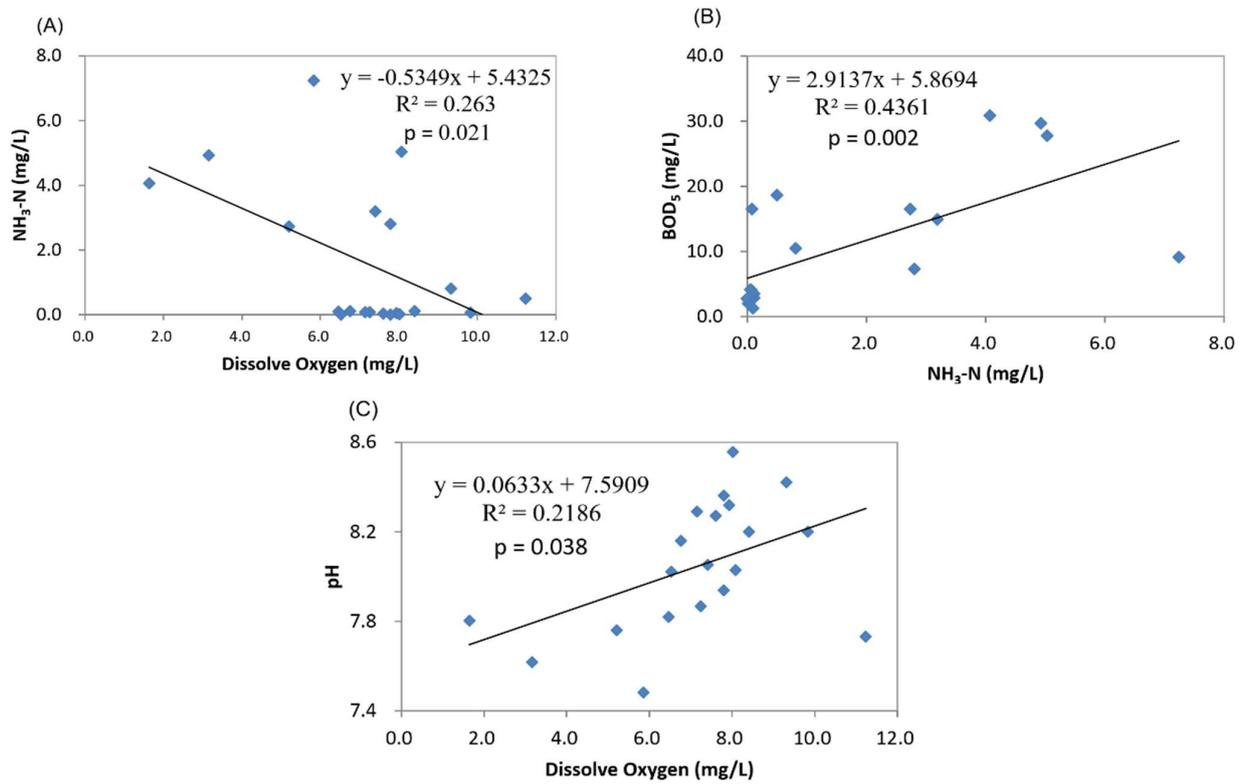


Figure 2. Correlations among selected seawater quality parameters across sites. Correlation plots are shown between NH₃-N and dissolve oxygen (A), BOD₅ and NH₃-N (B), and pH and dissolve oxygen (C).

Table 2. Total variance explained by PCA.

Component	Total	% of Variation	Cumulative %
1	3.41	26.25	26.25
2	2.18	16.78	43.03
3	1.55	11.90	54.93
4	1.29	9.91	64.84

Table 3. PCA loadings of seawater quality parameters.

	Component			
	1	2	3	4
Salinity	-0.872		-0.190	-0.167
SiO ₂	0.848		0.144	0.156
NO ₃	0.781			
Dissolved oxygen		0.959		
Oxygen saturation		0.958		
pH	-0.292	0.663		
SS	0.129		0.965	
Turbidity	0.155	-0.105	0.961	
PO ₄	0.122			0.836
NO ₂	0.286			0.749
NH ₃			0.128	0.586
BOD ₅	0.171		0.134	
Chl- <i>a</i>				

Table 4. Principal components and total variance explained (%). Sal.: salinity; Nut.: nutrient; DO: dissolved oxygen; N: nitrogen-based nutrients; P: phosphate; Si: silicon.

Component	1	2	3	4
All	Sal., Nut. (Si) (26.25)	DO (16.78)	Turbidity (11.90)	Nut. (N, P) (9.91)
Spring	Turbidity (22.10)	DO (18.37)	Sal., Nut. (Si) (14.79)	Nut. (N, P) (9.86)
Summer	Sal., Nut. (N, P) (33.50)	DO (16.81)	Turbidity (12.79)	Nut. (N) (8.44)
Fall	Sal., Nut. (Si) (27.55)	DO (18.58)	Nut. (N, P) (13.80)	Turbidity (12.11)
Winter	DO (25.62)	Sal., Nut. (Si) (20.45)	Nut. (N, P) (11.94)	Turbidity (9.49)
Dry season	DO (27.03)	Sal., Nut. (Si) (17.62)	Turbidity (13.14)	Nut. (N, P) (10.17)
Wet season	Sal., Nut. (N, Si) (27.68)	DO (16.72)	Turbidity (12.60)	Nut. (N) (9.14)

CA was also used to assess similarity across sampling sites, and three clusters were identified (Figure 3A); these clusters were supported by a discriminant analysis (i.e., CCA; Figure 3B and Table 5). Based on the data, the three clusters appear to be linked to anthropogenic impact. The “weak” group (Figure 3B), which featured high salinity and low nutrient levels consisted of Wan-Li-Tung, Bai-Sha, nuclear power plant outlet (NPP-OL), Nan-Wan, Tan-Zi, Tsuan-Fan-Shir, Sar-Dau, and Long-Keng. The “strong” group was characterized by low salinity and high nutrient levels and included Kenting and Banana Bay. The remaining sites fell within the “medium” group (Hou-Wan, Hou-Bi-Hu, Caesar, and others). Thirteen of the fourteen groups were classified correctly by the corresponding model (Table 6); Banana Bay was incorrectly classified, possibly due to its low salinity. In summary, then, we documented higher anthropogenic nutrient input in the summer rainy season, and study sites clustered by degree of nutrient loading. Those sites near major freshwater discharge areas were particularly affected by high nutrient loads.

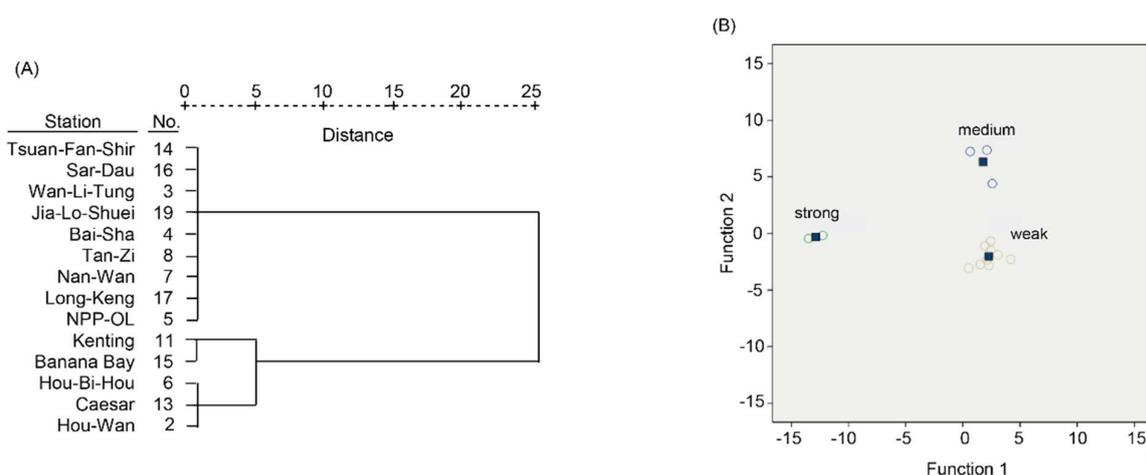


Figure 3. Hierarchical clustering and canonical correlation analysis of seawater quality data across sites. In the cluster tree (A), relative distances are shown, and in the CCA biplot (B), the mean (centroid) for each group is indicated by a square.

Table 5. Canonical correlation analysis.

Canonical	Eigenvalue	% of Variance	Cumulative %	Canonical Correlation
1	35.283	71.1	71.1	0.986
2	14.346	28.9	100	0.967
Test of function(s)	Wilks' lambda	Chi-square	df	p-value
1 through 2	0.002	53.739	12	<0.01
2	0.065	23.212	5	<0.01

Table 6. Confusion matrix of classification results. In total 13 or 14 samples were correctly classified by the model.

	Cluster Case Number	Predicted Group Membership			Total	
		Medium	Strong	Weak		
Training model	Actual	medium	3	0	0	3
		strong	0	2	0	2
		weak	0	0	9	9
	%	medium	100	0	0	100
		strong	0	100	0	100
		weak	0	0	100	100
Validation model	Actual	medium	3	0	0	3
		strong	0	1	1	2
		weak	0	0	9	9
	%	medium	100	0	0	100
		strong	0	50	50	100
		weak	0	0	100	100

4. Conclusions

The results of PCA indicated anthropogenic-nutrient-input from household waste water discharge were main pollution impact to the seawater quality of Kenting reef area in the past 20 years, especially in the rainy season of summer. CA and DA further revealed the strong nutrient impact was confined to the sampling sites with local discharge outlets after analysis with 14 sampling sites. With the increasing tourism pressure to KNP, tourist number control, waste water treatment and increase of land protection facility are the urgent concern to reduce and further the anthropogenic impact to the coral reef ecosystem in KNP.

Supplementary Materials: The following supporting information can be downloaded at: <https://www.mdpi.com/article/10.3390/jmse10020270/s1>, Supplementary Data for Figure 2, Tables 2 and 3.

Author Contributions: Conceptualization, C.-C.C., J.-T.W. and P.-J.M.; methodology, P.-J.M.; software, H.-Y.H. and C.-M.C.; field work and analysis, C.-M.C.; writing—original draft preparation, J.-T.W. and P.-J.M.; writing—review and editing, A.B.M.; supervision, J.-T.W. and P.-J.M.; project administration, P.-J.M.; funding acquisition, P.-J.M. and C.-C.C. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: All data are provided in Supplementary Materials.

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